Michigan's Dangerous Currents Initiative: The Research

Field Research and Satellite Analysis of Nearshore Currents

Guy Meadows
Michigan Technological University
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…and many others at
Great Lakes Research Center (GLRC)
Michigan Tech Research Institute (MTRI)
and University of Michigan

Great Lakes Regional Meeting
NOAA Coastal Management Program
September, 2015

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Coastal Framework:
Great Lakes vs. Ocean coasts

- Classic wisdom (Scripps):
  - Sheppard et al., 1941; Sheppard & Inman, 1950
  - Bowen, 1969; Bowen and Inman, 1969
- West Coast research dominated rip current theory
  - Long period swell
  - Surf beat
  - Pocket beaches
  - "Mellow waves"
- Organized incident waves ➔ Organized nearshore flows - Rips

Swell vs. Sea

Great Lakes:
Dominated by locally generated seas

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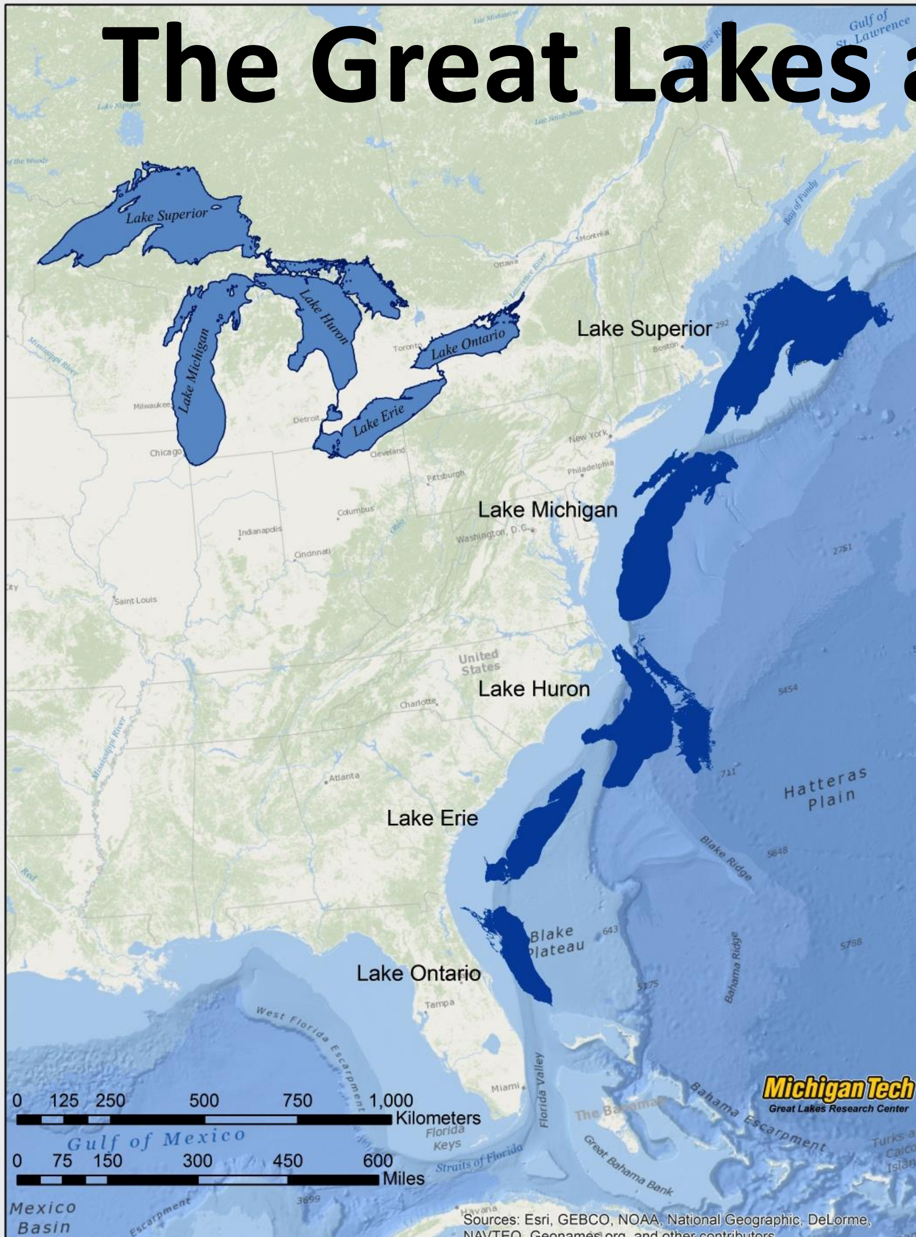
The Great Lakes are Inland Seas



- Each Lake occupies a region the size of several East Coast states.
- Fetch lengths are large
- Wind speeds are large
- Air/Sea ΔT are large
- Waves are large

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Beaches change quickly…

- Above the water
- On the water and
- Below the water

St Joseph, MI

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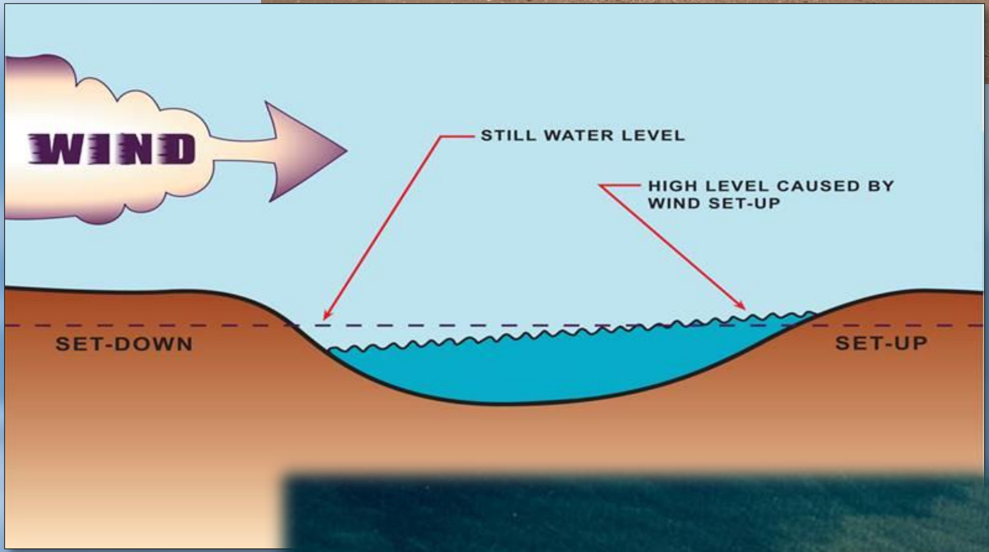
Great Lakes Dynamics

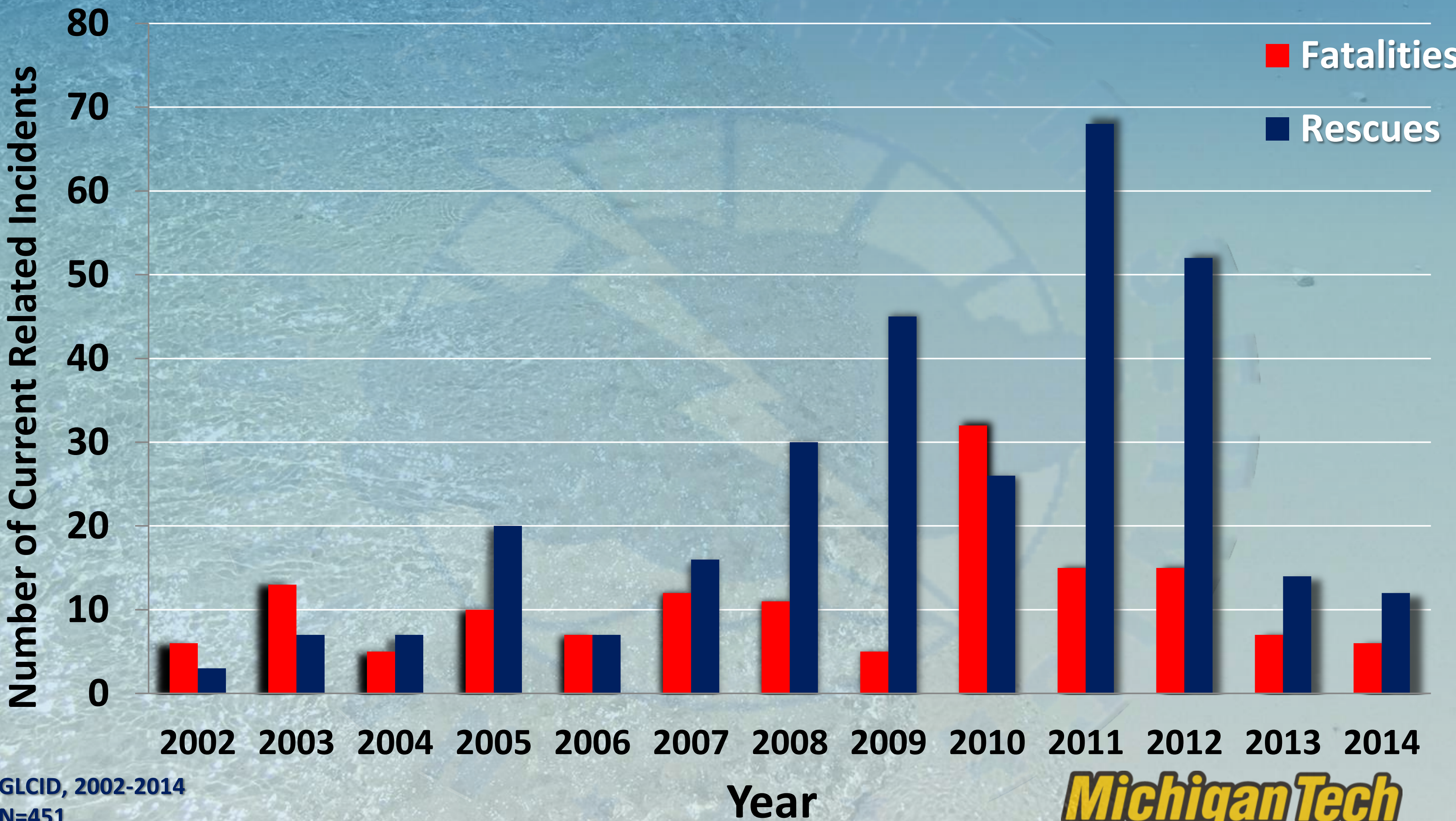
- Locally generated seas accompanied by very strong and rapidly evolving wind fields
- Small astronomical tides, but large "wind tides" Seiches
- Producing strong, rapidly evolving: Dangerous Nearshore Currents (DNCs)
  - Longshore currents
  - Rip currents
  - Structural currents
  - Outflow currents (drown river mouths)

Great Lakes Dynamics



Current Related Incidents 2002-2014

NWS Database Victims Conditions Current Types Conclusions



GLCID, 2002-2014
N=451

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Dangerous Nearshore Waves and Currents
(MDEQ funded)

Three components:

1. Rip Currents in the Great Lakes: Advancing Forecasting through Perishable Data Recovery

1. Remote Sensing-based Detection and Monitoring of Rip Currents in the State of Michigan

1. Implementation at Michigan State Parks

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(1) Rip Currents in the Great Lakes: Advancing Forecasting through Perishable Data Recovery

- Three Test sites
  - Hwy 2 Northern Lake Michigan
  - Grand Haven State Park
  - Holland State Park

- Fall 2012 – Hwy 2 – Equipment Tests

- Spring 2013 (May 13 – 24) & Spring 2014 (May 11- 17)
  - Grand Haven State Park
  - Holland State Park

- Fall 2013 (Sept 16 – 19)
  - Hwy 2 Northern Lake Michigan

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The overall research program is designed test two scientific hypotheses:

- **Hypothesis 1:**
  - Wind induced seiching in the enclosed basins of the Great Lakes is dynamically similar to tidal height variations on open ocean coasts in intensifying wave generated rip currents.
- **Hypothesis 2:**
  - On barred beaches rip spacing is not related to characteristic dimensions of the incident wave field or pre-existing morphology of the beach and nearshore system.

Fall 2012 – Hwy 2 – Equipment Test

September 24 – 28, 2012

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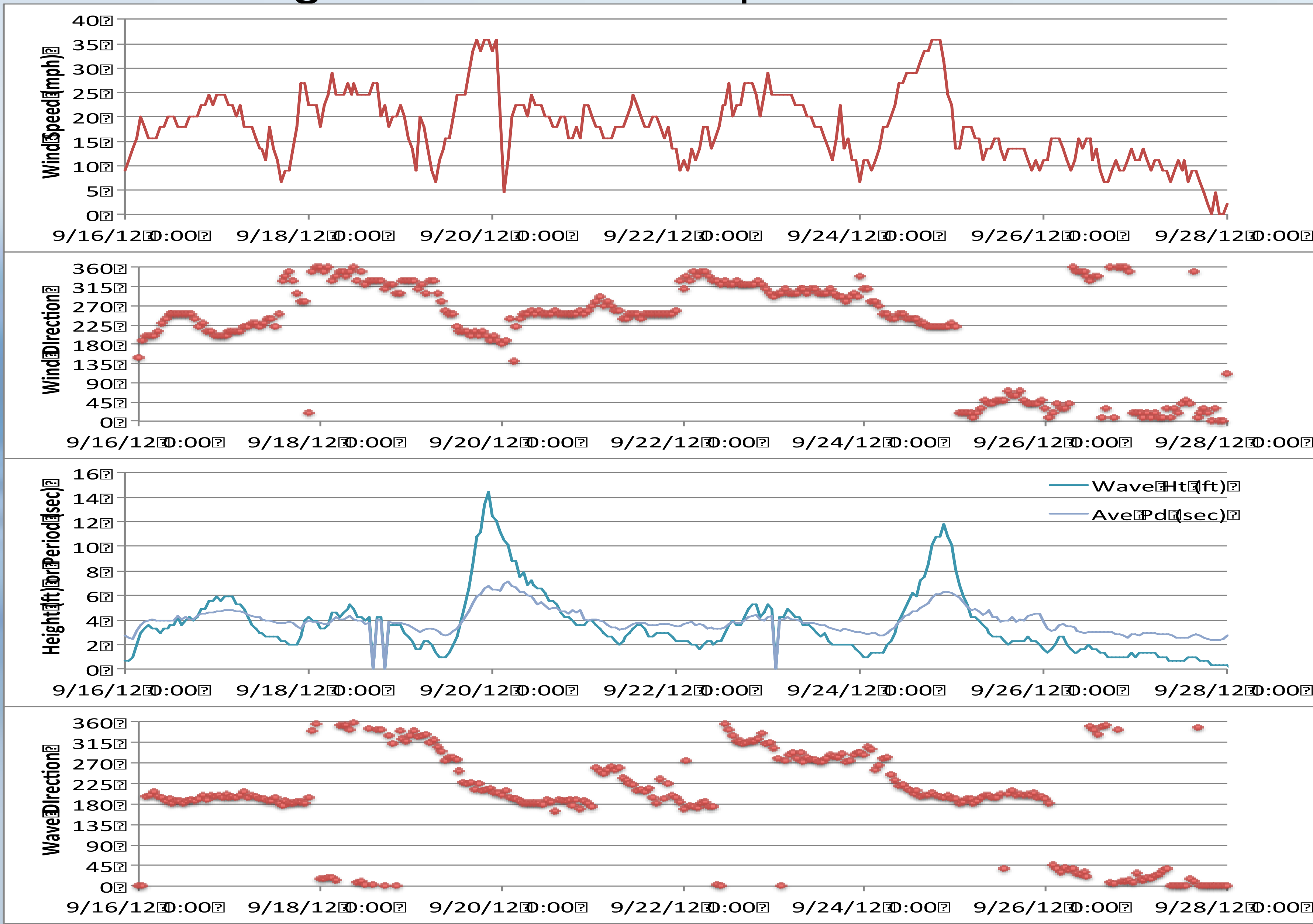
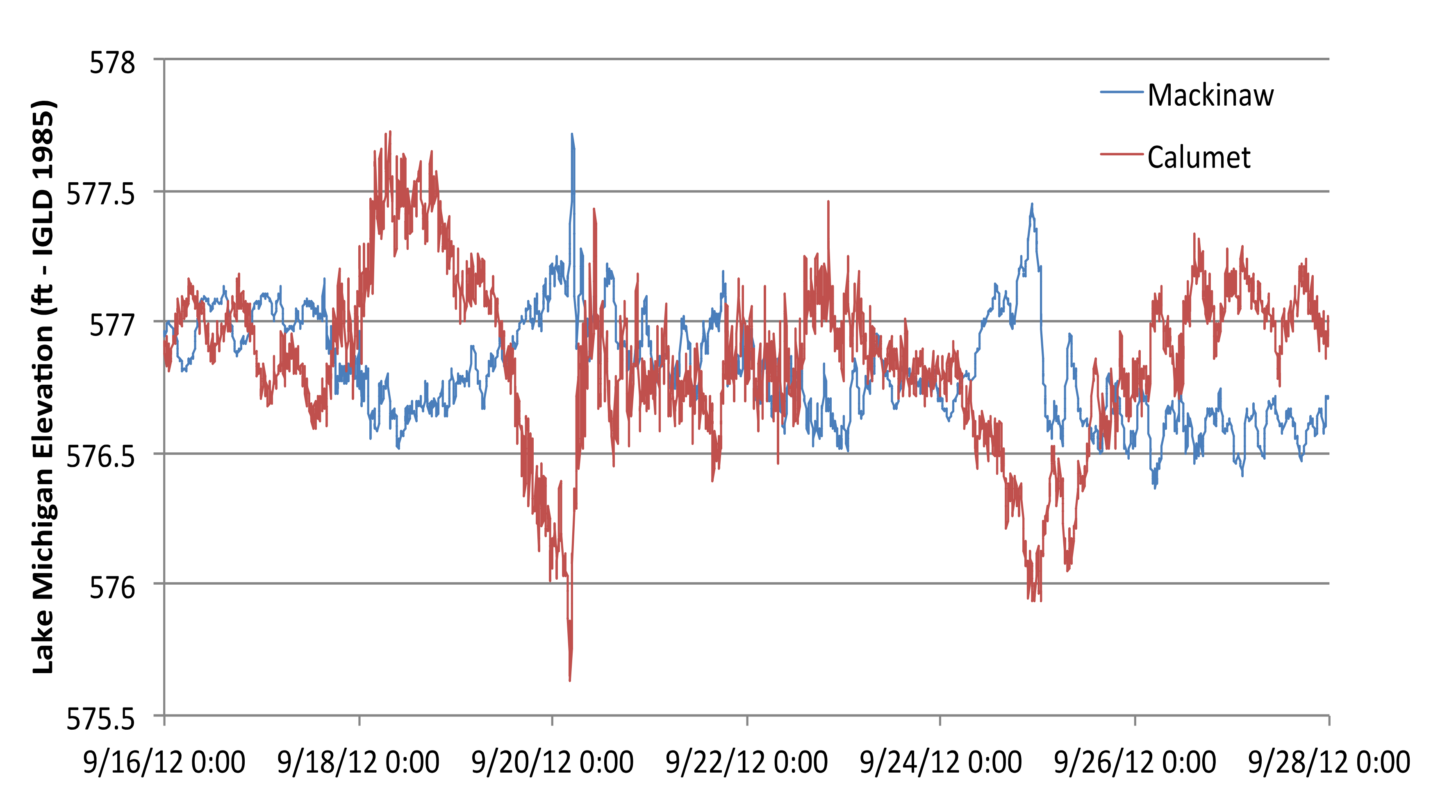
Environmental Conditions:
Significant Storms Sept. 19 & 24-25



Environmental Conditions: Significant Storms Sept. 19 & 24-25



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Environmental Conditions:
Significant Storms Sept. 19 & 24-25

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Perishable Data
Bathymetry – Three ways

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BathyBoat


N
2
© 2013 Google
Image © 2013 TerraMetrics
Image © 2013 DigitalGlobe
Google earth
Imagery Date: 6/14/2011 45°56'30.72" N 84°55'43.47" W elev 579 ft eye alt 5499 ft

Autonomous Underwater Vehicle (AUV)

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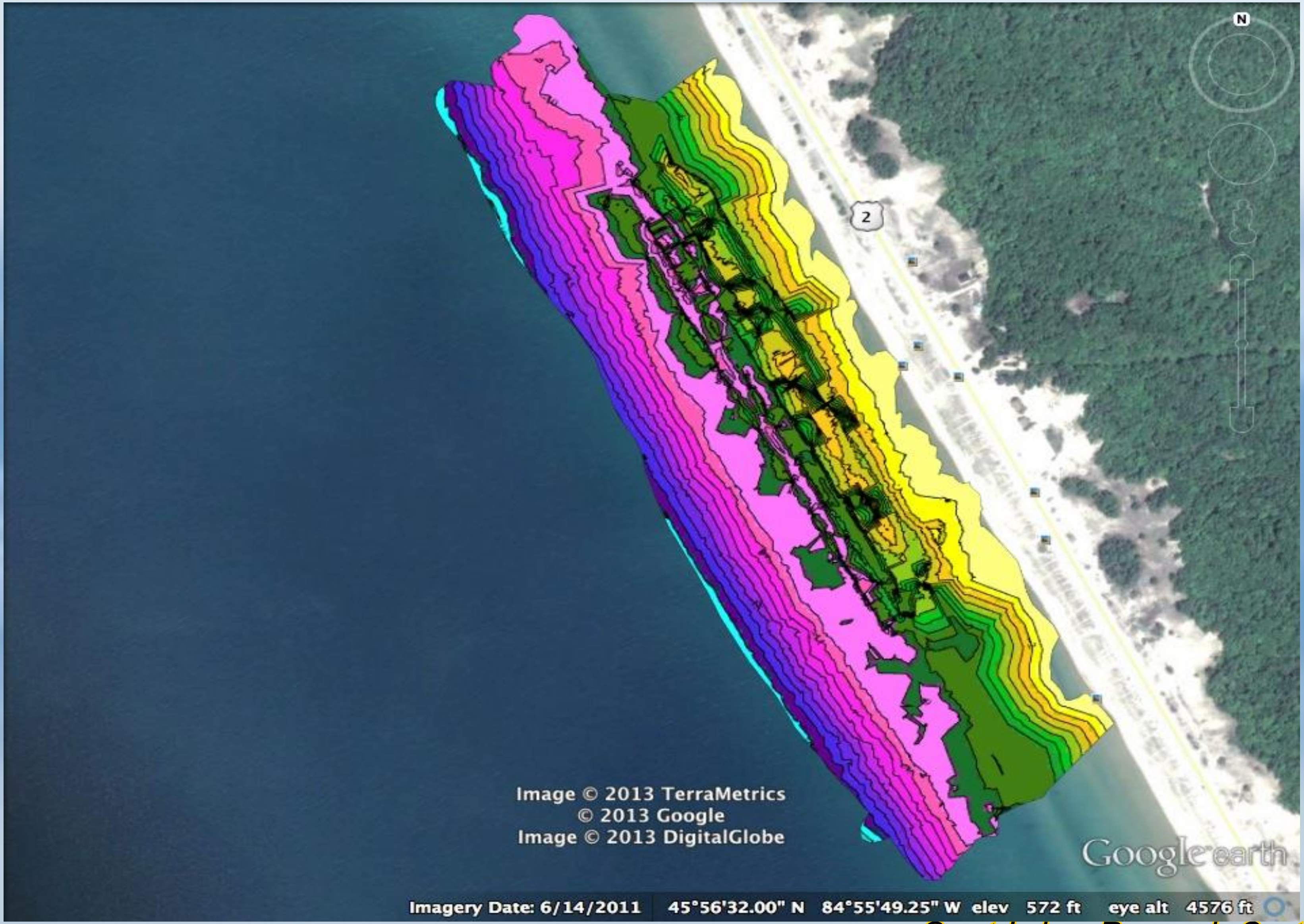
Composite Bathymetry



GPS Drifters and New Radar (MTRI)

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HWY 2 - Radar Measurements

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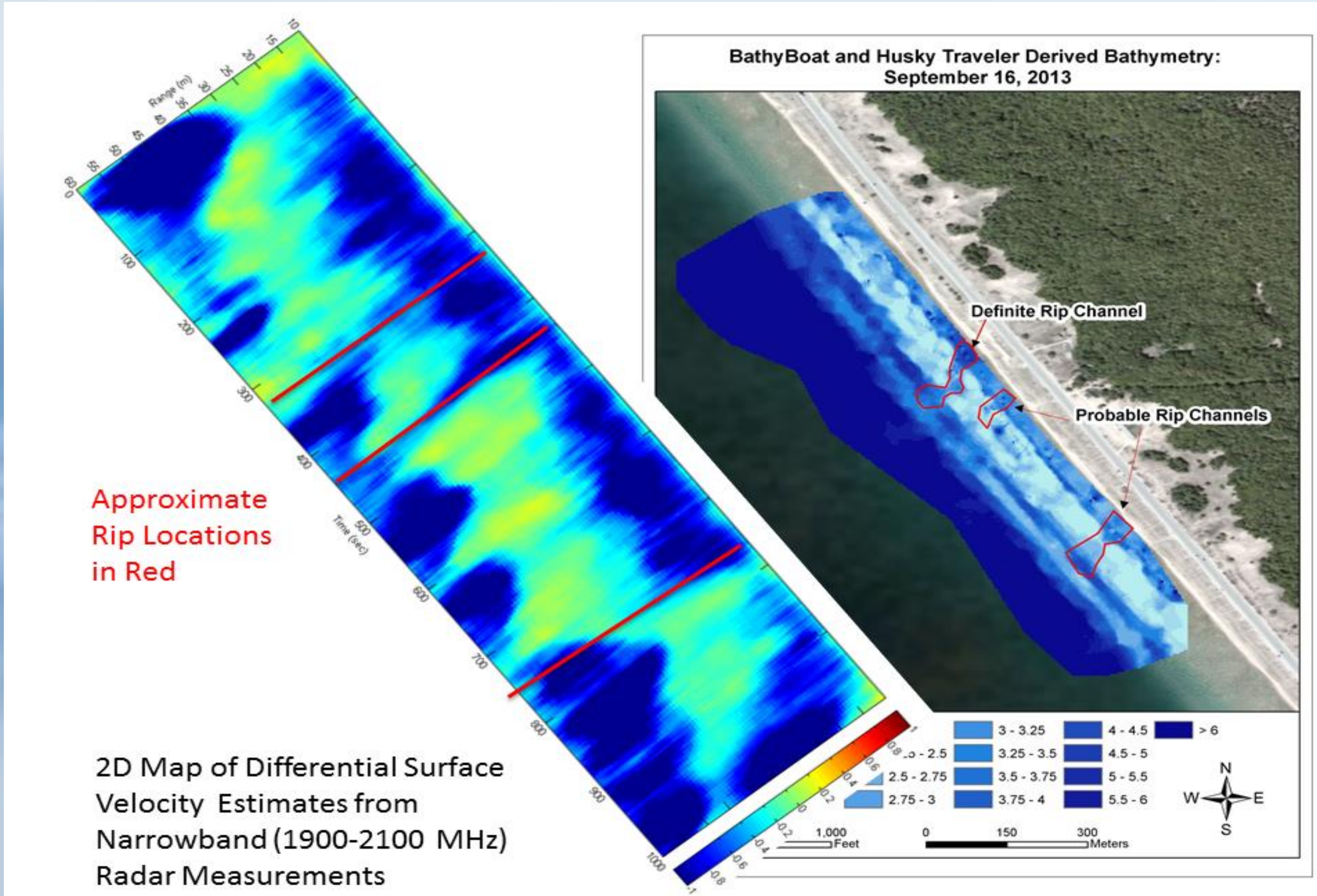
Promising Radar Results



2D Map of Differential Surface Velocity Estimates from Narrowband (1900-2100 MHz) Radar Measurements

Winter HWY 2

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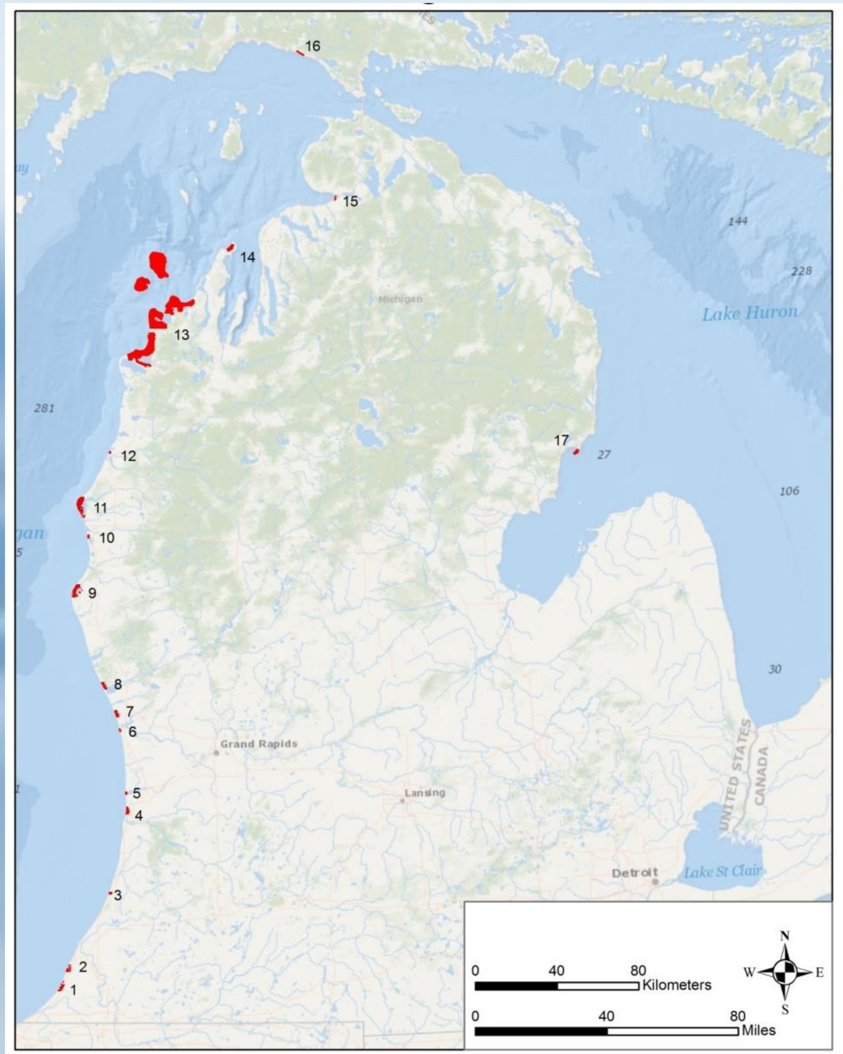
(2) Remote Sensing Project Goals

- Identify areas within Michigan State Park beaches that are prone to rip currents
  - Compile aerial/satellite imagery of State Park beaches
  - Heads-up digitization of rip channels visible in imagery to characterize persistence
- Improve the understanding of the physical features associated with rip current formation



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Collected Nearshore imagery for 17 State Parks

	Warren Dunes	Holland	Grand Haven	Hoffmaster	Ludington	Hwy 2 State land near St. Ignace	Tawas Point	Sleeping Bear Dunes	Grand Mere
Images Acquired	11	11	12	13	8	8	11	11	10
Usable images	9	9	10	9	7	7	9	10	8
Images with rip-associated features	7	8	5	8	6	7	3	8	2

	Muskegon	Saugatuck Dunes	Silver Lake	Mears	Petoskey	Leelanau	Van Buren	Orchard Beach
Images Acquired	9	11	8	8	8	8	9	10
Usable images	7	8	7	7	7	7	7	7
Images with rip-associated features	6	3	4	6	7	5	4	5

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Threat level classification

Frequency of rip feature presence	Threat level
> 50%	High
25 – 50%	Medium
< 25 %	Low
No rip features observed in any image	No Threat

Final products:

- Heat maps of long-term rip persistence (1998 – 2012)
- Color-coded threat levels

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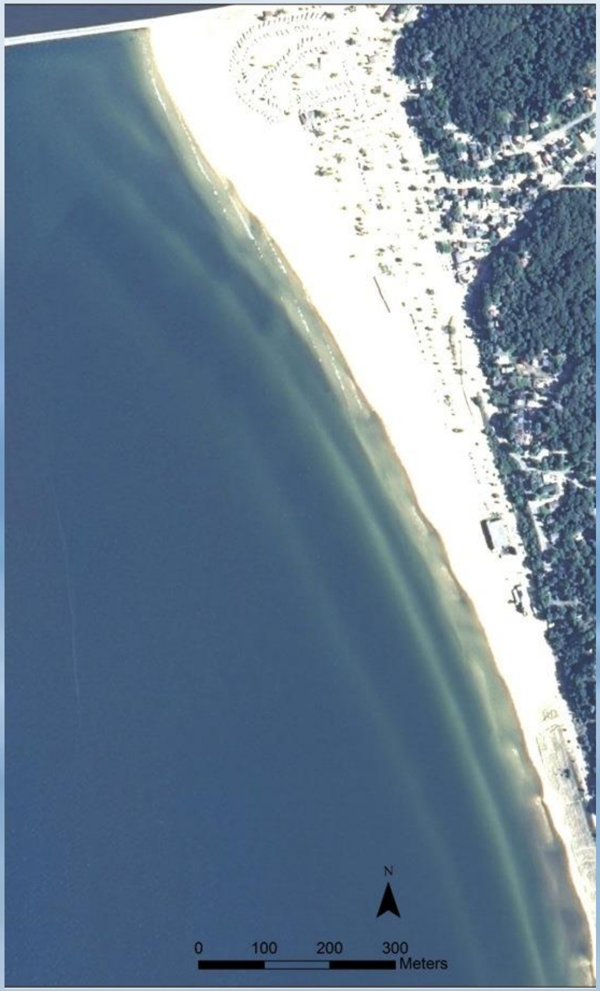
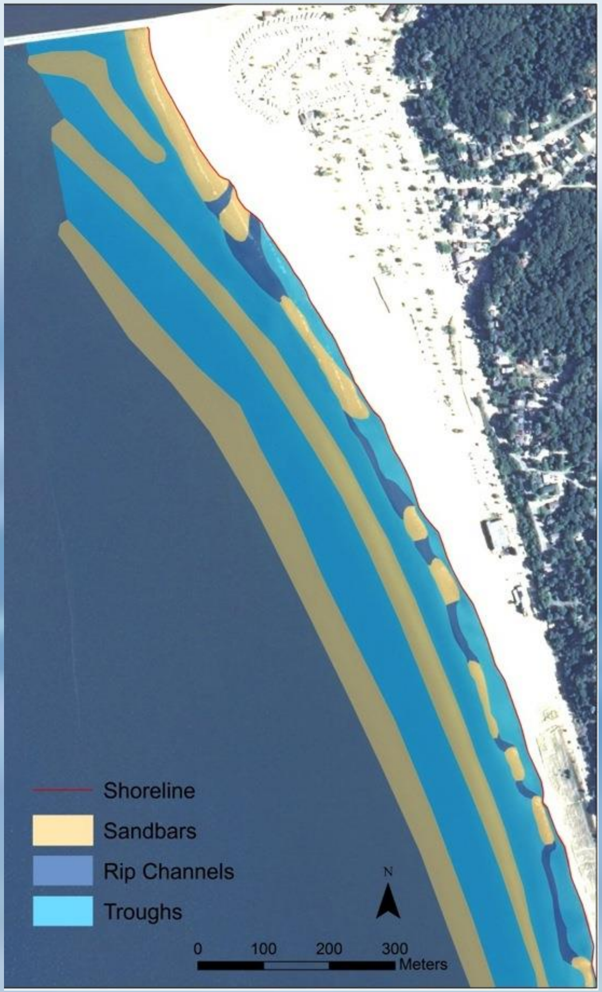
Example: Grand Haven State Park





Heads-up digitization of longshore sandbars and rip channels

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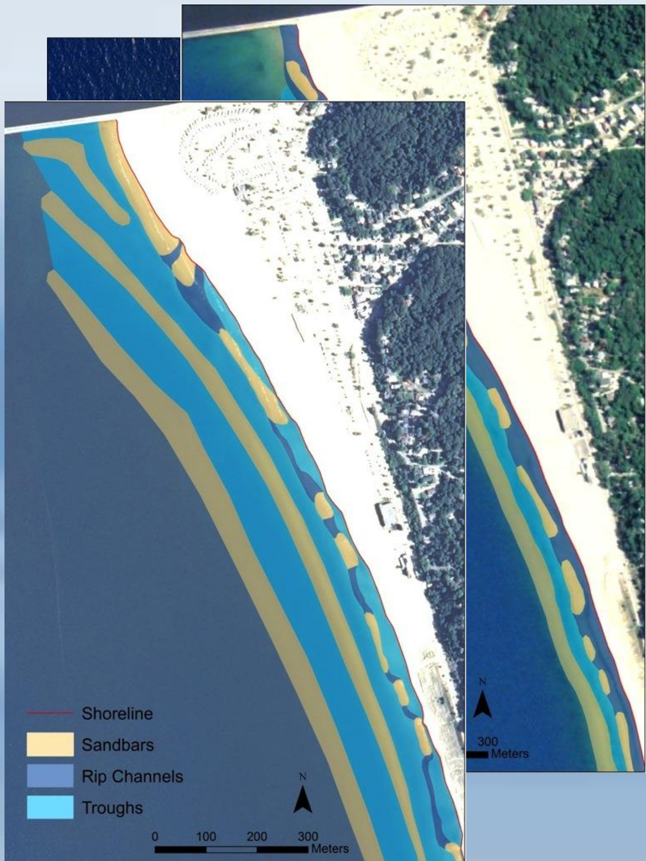
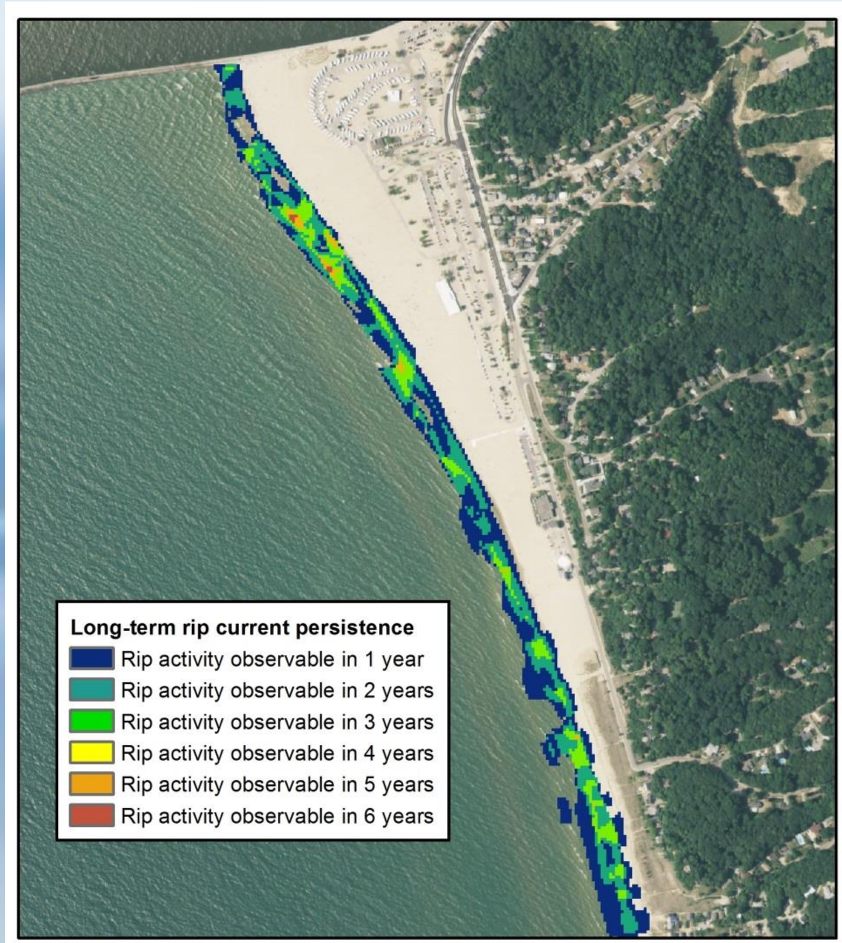
Compilation of all digitized features into a “heat map” of rip channel locations from 1998-2012





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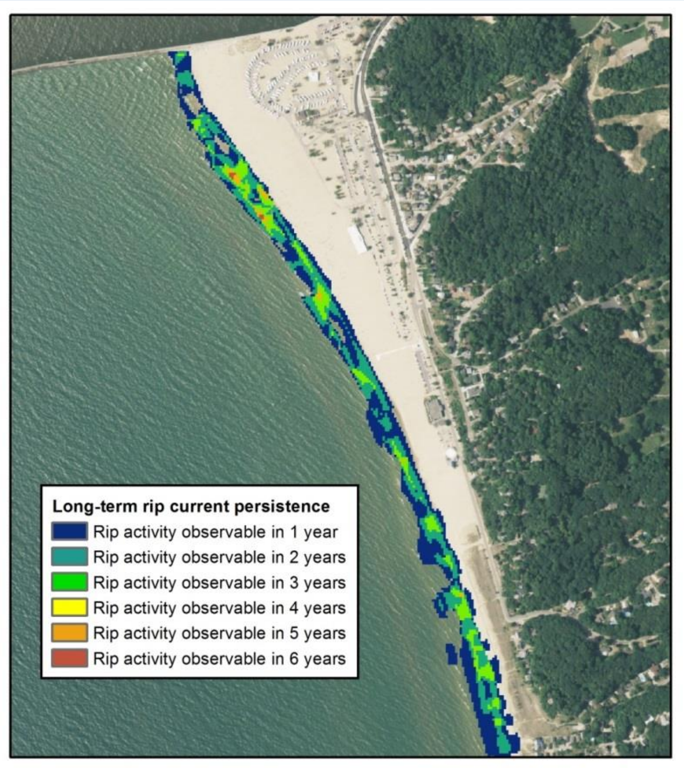
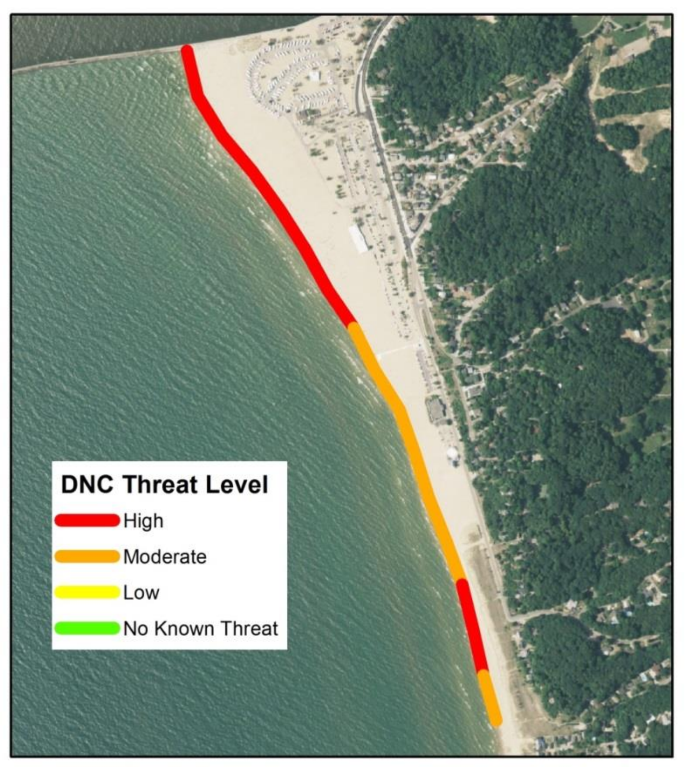
Areas with higher rip channel persistence were assigned higher threat levels





Frequency of rip feature presence	Threat level
> 50%	High
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< 25 %	Low
No rip features observed in any image	No Threat

Lake Michigan rip current patterns

- Rip channel spacing
  - Statewide aerial imagery sets collected at different times were compared to evaluate the effect of changes in lake level on the spacing of rip channels
- Beach slope
  - Beaches where rip channels form frequently were compared to those where they do not in order to look at how beach slope affects rip current formation

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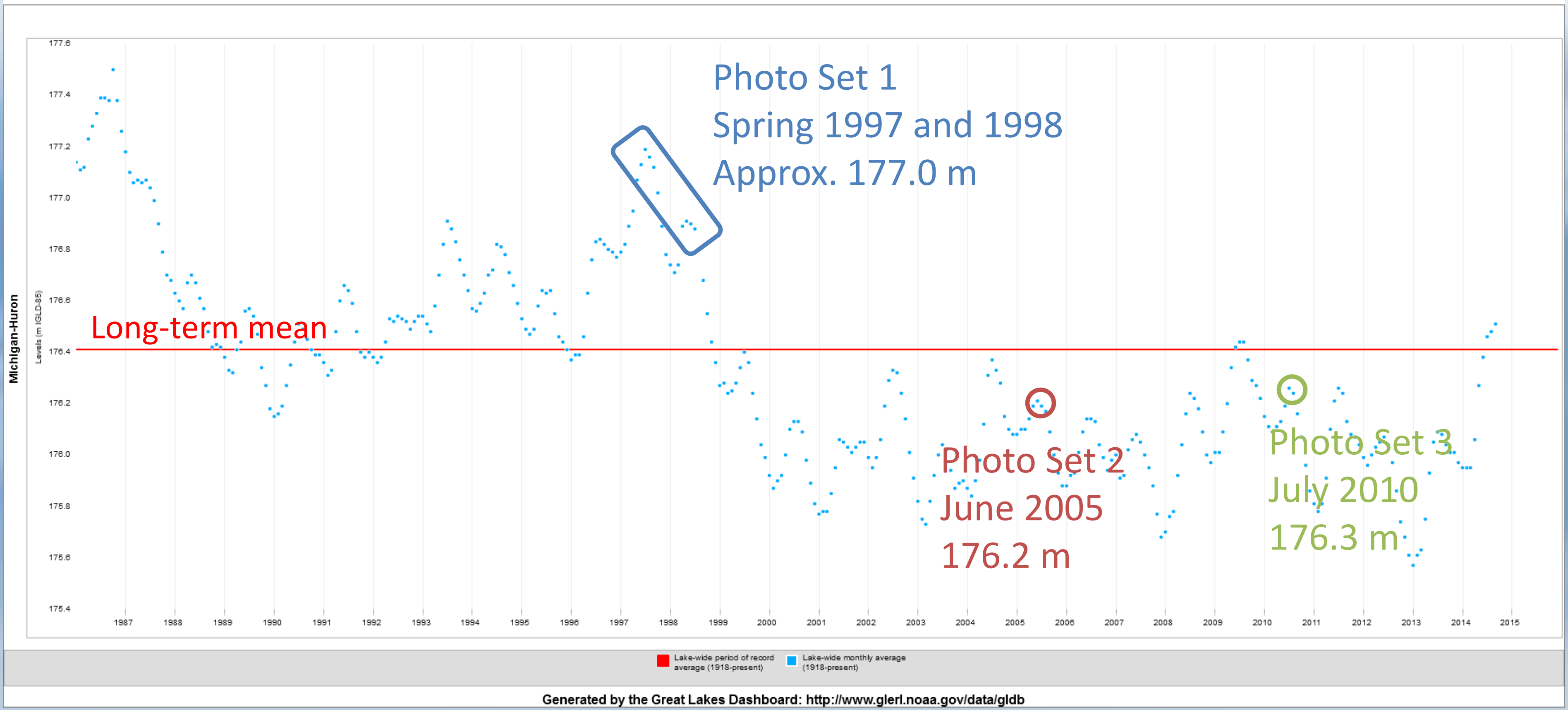
Rip Spacing vs. Changing Lake Level

Michigan-Huron Lake-Wide Water Level
(monthly average, meters above sea level)



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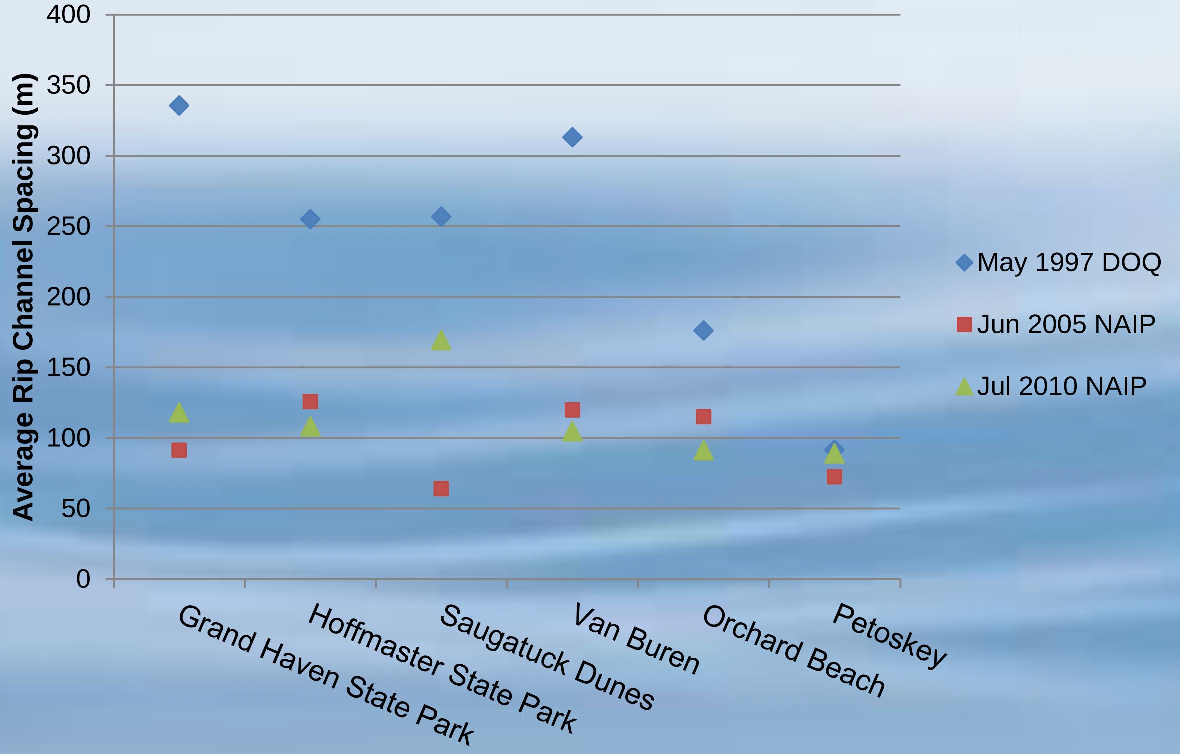
Rip Spacing vs. Changing Lake Level



On average, rip channel spacing across all sites was significantly wider in 1997 (higher water level) than in 2005 ($p = 0.011$) or 2010 ($p = 0.013$) (lower water levels).

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Beach Slope

- On the Great Lakes, the shape of a beach is controlled by the local wave conditions, sediment and geology
- On ocean coasts, it has been observed that beaches with intermediate slopes (~5-10°) are the most dynamic and pose a greater hazard related to nearshore currents than steeper or flatter (reflective or dissipative) beaches.

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Beach Slope

- Recent bathymetric LIDAR data collected along the Great Lakes coasts by USACE over the last decade allows us to compare the slopes of beaches with and without frequent rip current activity

- For each beach, a profile was generated of the change in elevation of the lake bottom moving perpendicularly offshore

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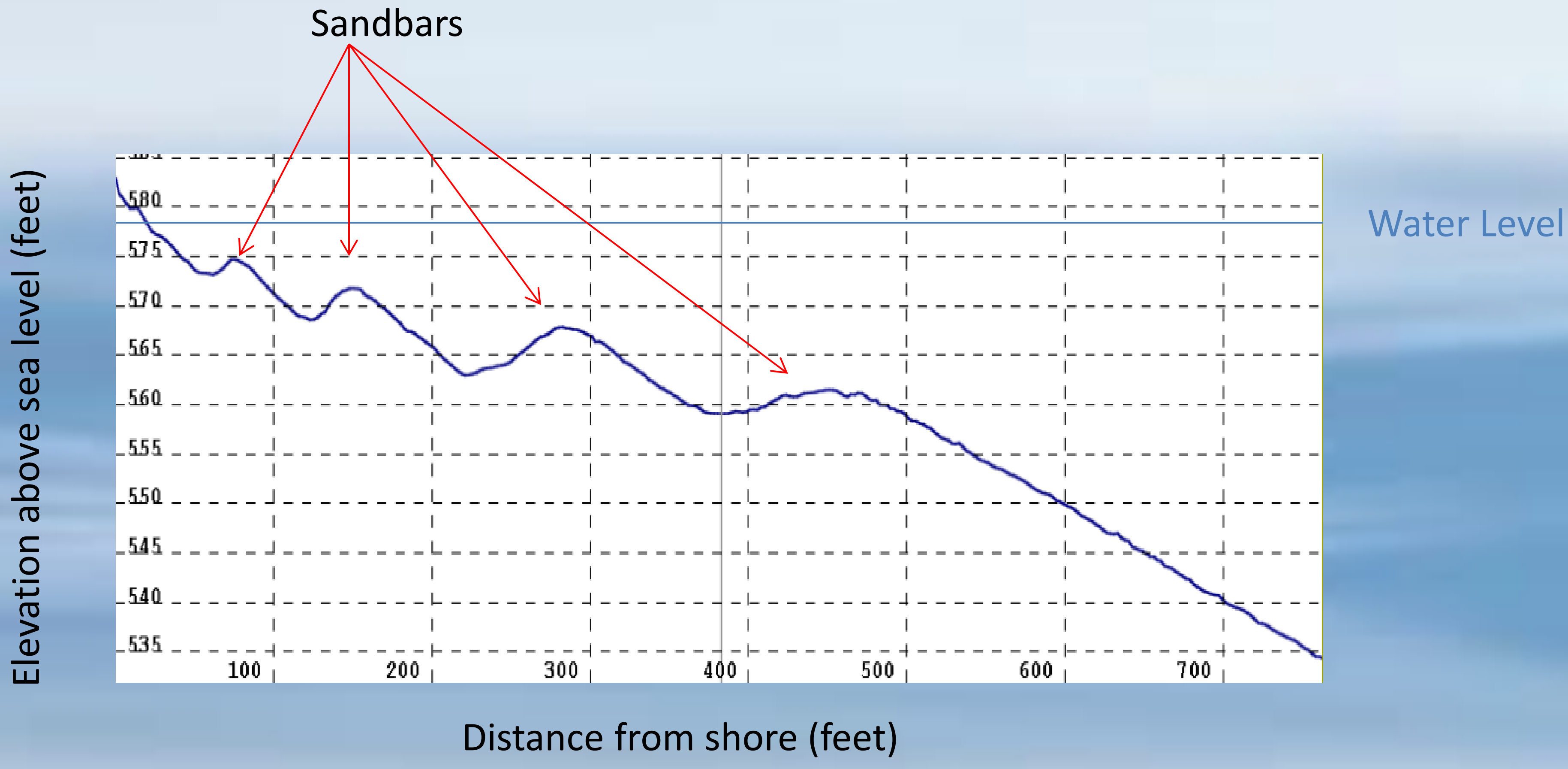
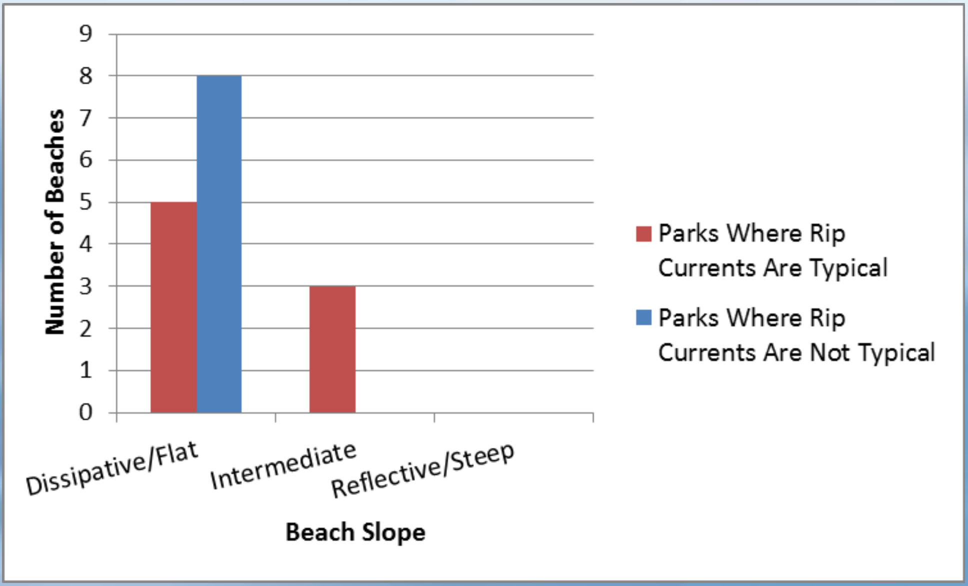
Beach Slope


Sandbars
Water Level
580
575
570
565
560
555
550
545
540
535
100
200
300
400
500
600
700
Elevation above sea level (feet)
Distance from shore (feet)

Beach Slope

- 8 State Park beaches where rip currents are a known and frequent hazard were compared to 8 parks where they are not
- Beaches with frequent rip currents tend to be more sloped, but most beaches in both groups are fairly flat
- The three parks with intermediate slopes (Grand Haven, Holland, Petoskey) are some of the most hazardous for rip currents



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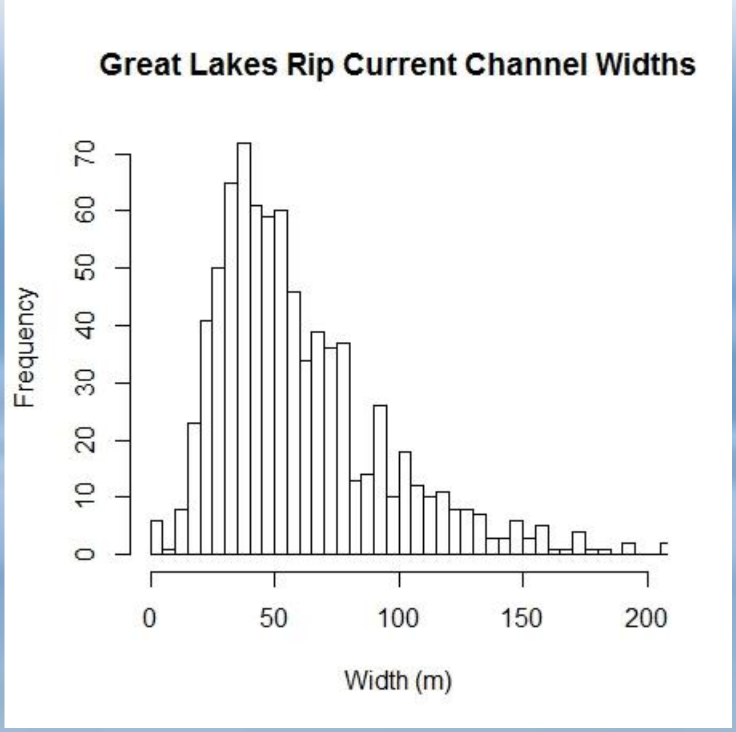
Great Lakes Rip Current Dimensions



- Overall, our dataset of digitized rip current channels (n=916) shows that rip channels in the Great Lakes tend to be 20-100 m wide (median 51 m).
- Shallow depressions, not steep cuts.

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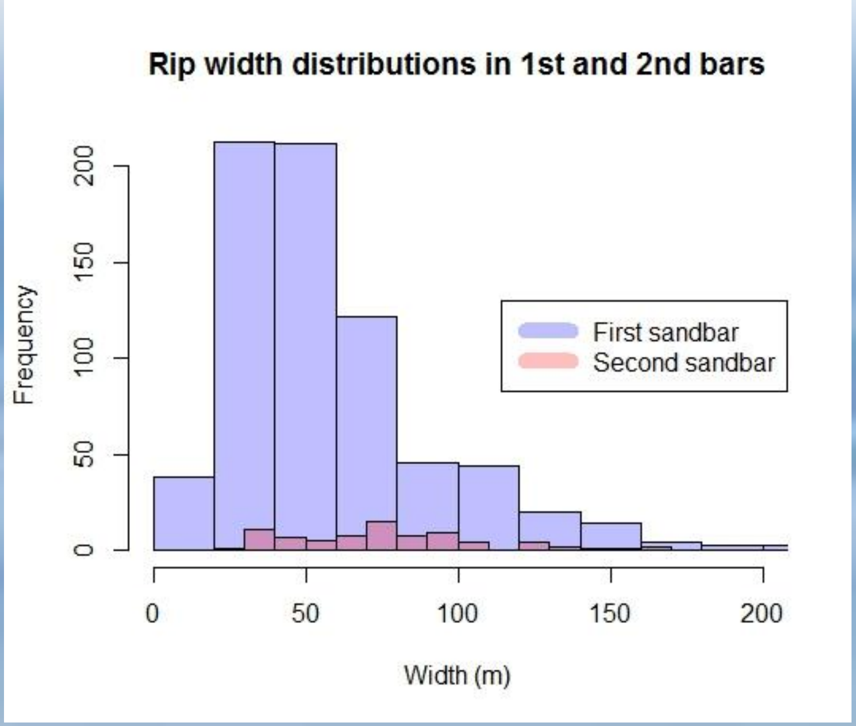
Great Lakes Rip Current Dimensions



- Rip Channels through the second sandbar were observed much less frequently than in the first sandbar, both because the first sandbar is more active and because water clarity can limit visibility of the second bar

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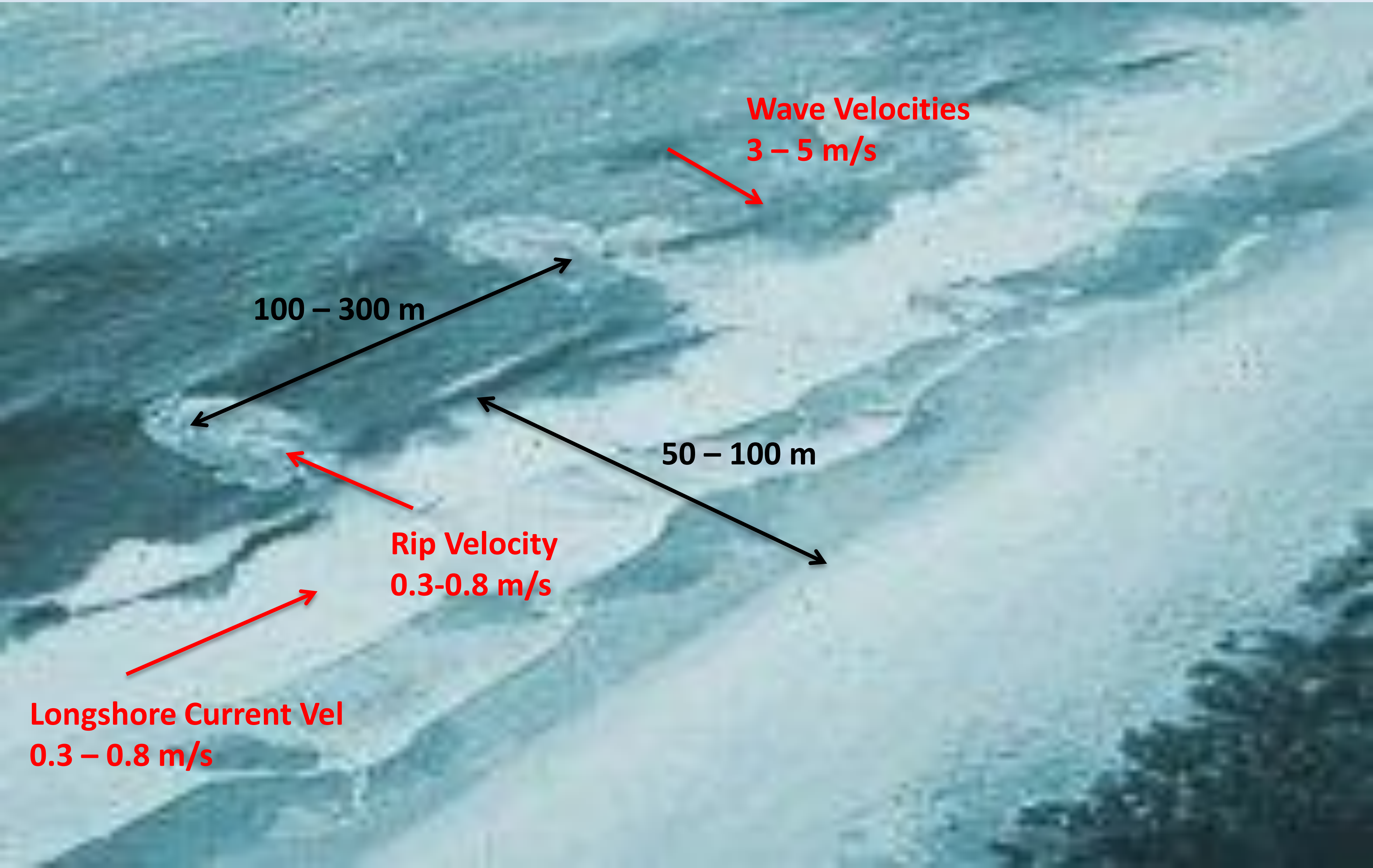
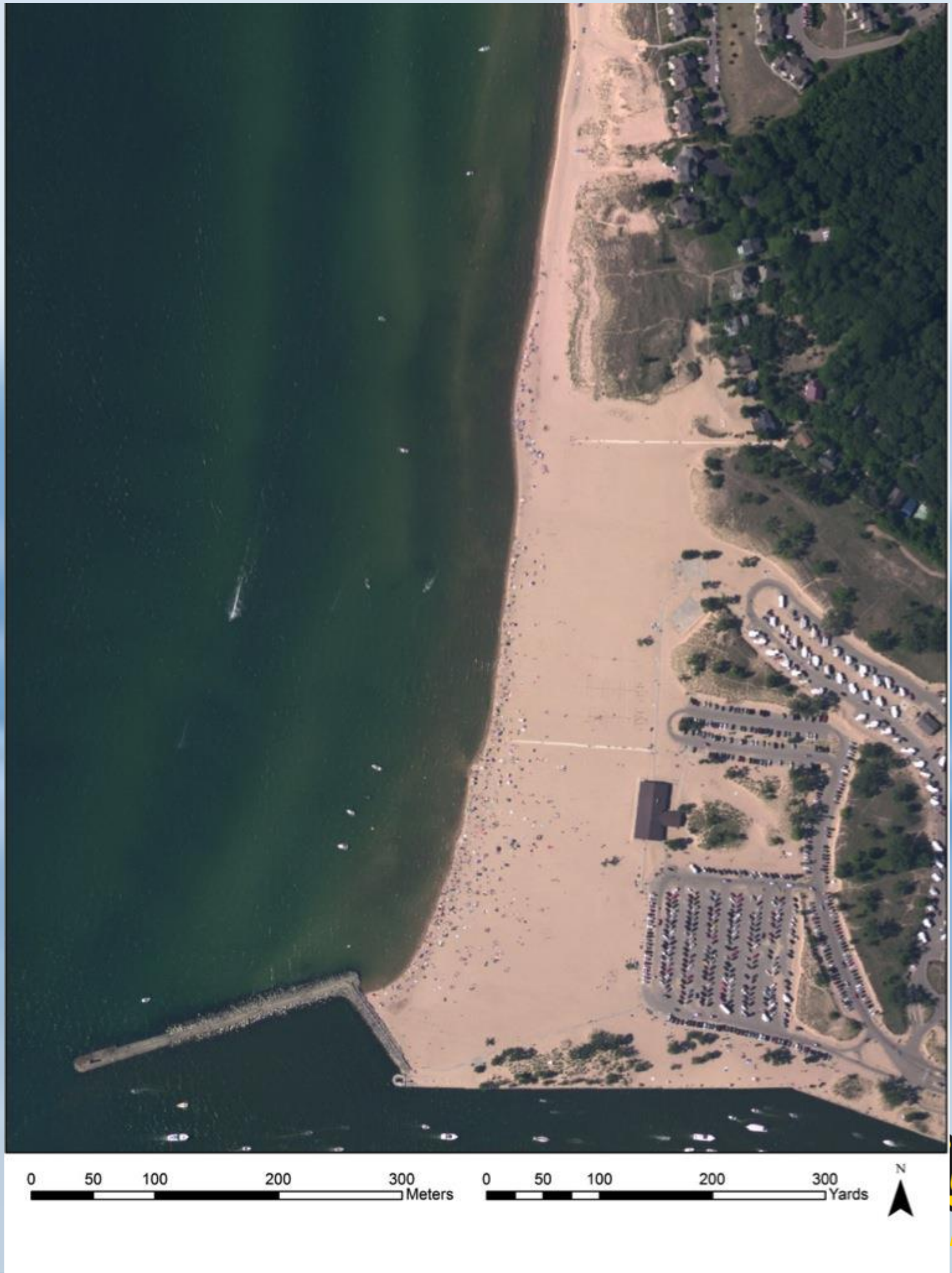
Typical Great Lakes Rip Dimensions and Velocities



Holland State Park, Summer 2011



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Results…

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Michael vs. Drifters

Michael Phelps:

Career Best 100 m Freestyle

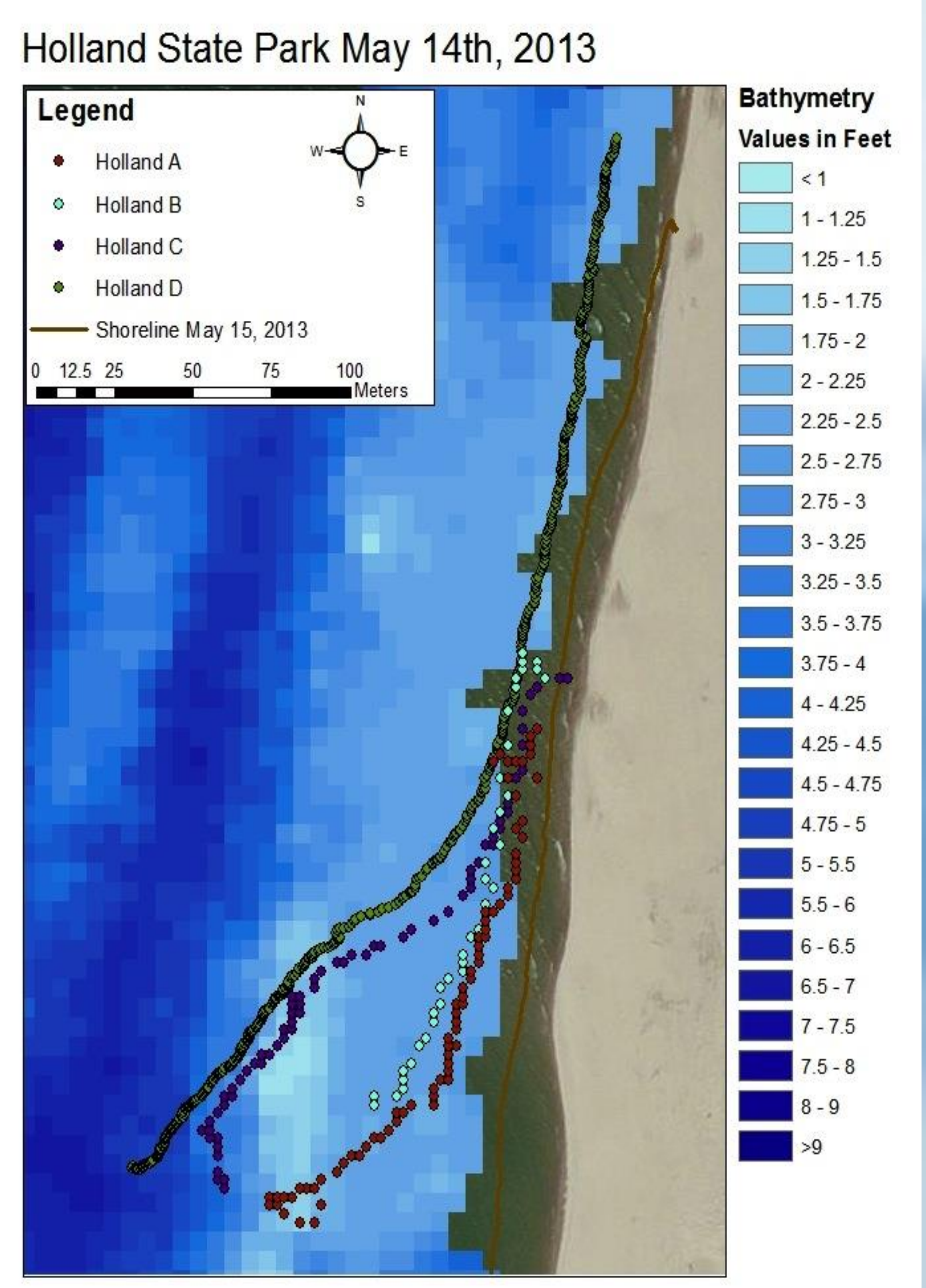
– 47.51 s → 2.1 m/s

4.7 mph

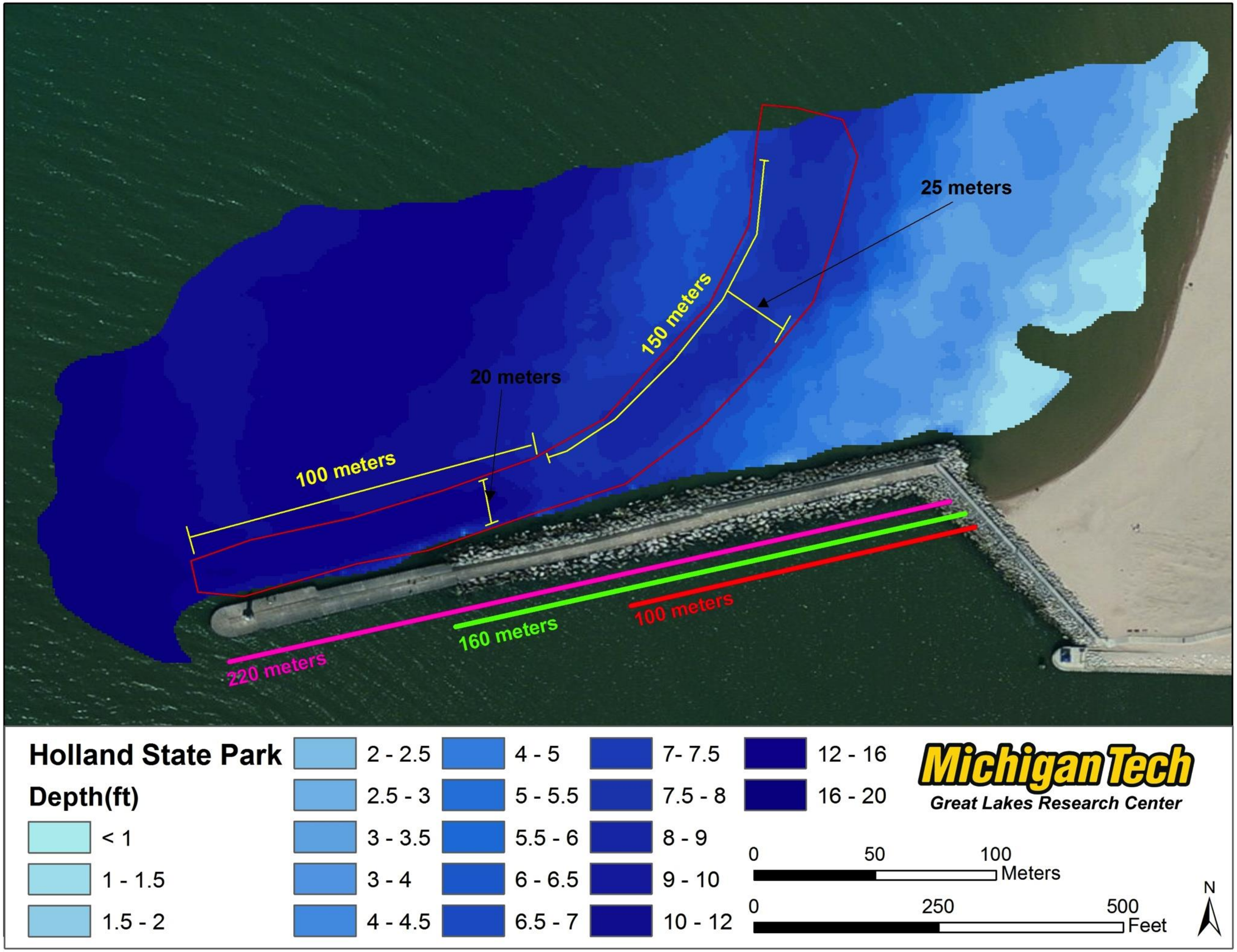
6.9 fps (~ 1 body length/second)

- Holland State Park – Drifter Floats beach with no bathymetic features indicating rip current activity, drifters travelled consistently along the shoreline.

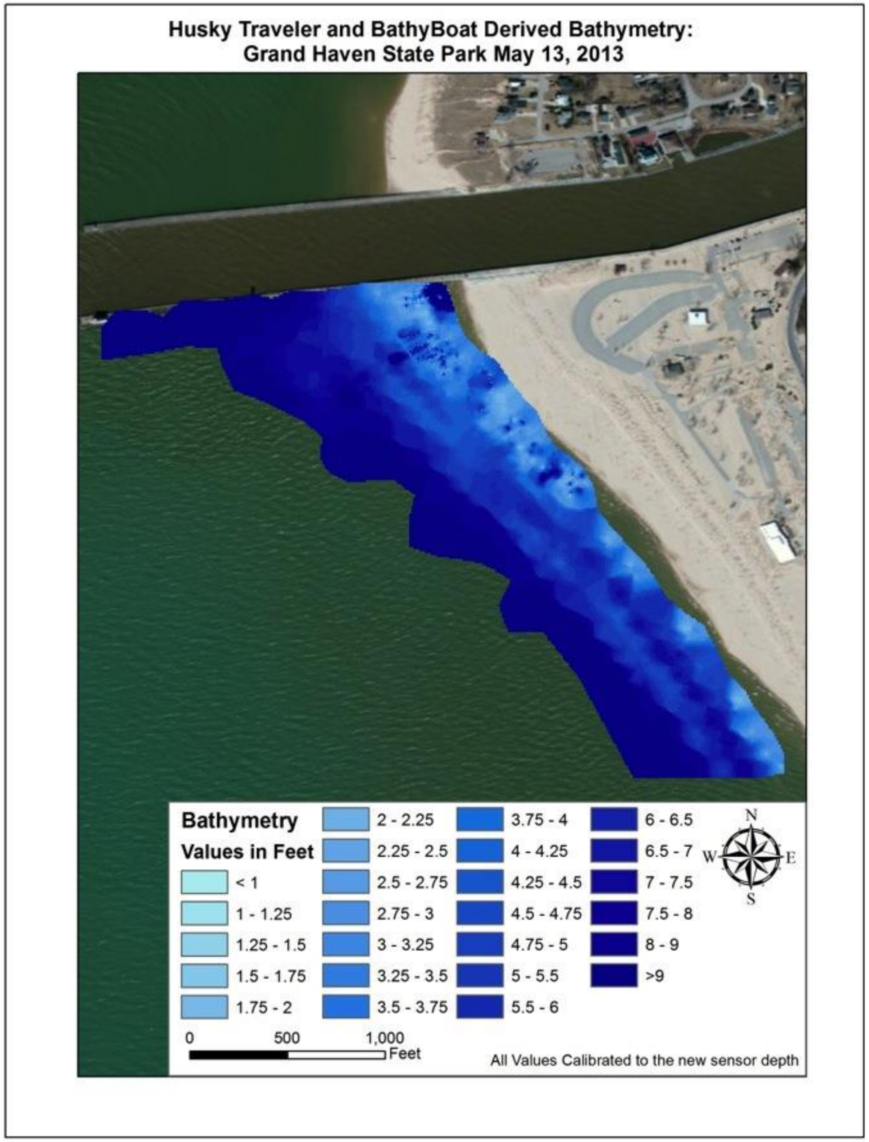
Site	Holland A	Holland B	Holland C	Holland D
Average Velocity (m/s)	0.45	0.50	0.20	0.30
Maximum Velocity (m/s)	1.71	3.00	2.00	1.41
Distance From Shore: Start (m)	53.64	29.94	64.22	86.00
Distance From Shore: End (m)	3.21	3.51	0.00	16.31
Travel Time (min)	8.25	7.22	15.65	21.47

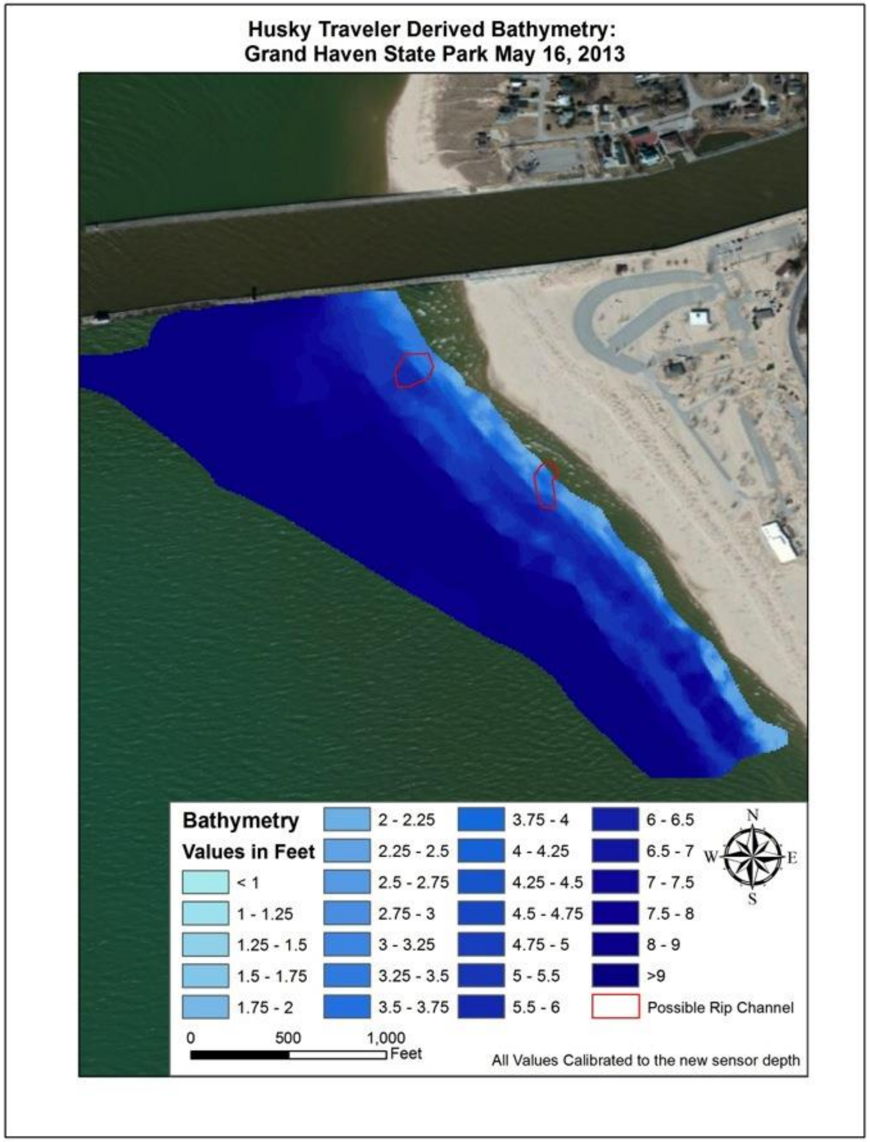


Holland State Park, Summer 2011



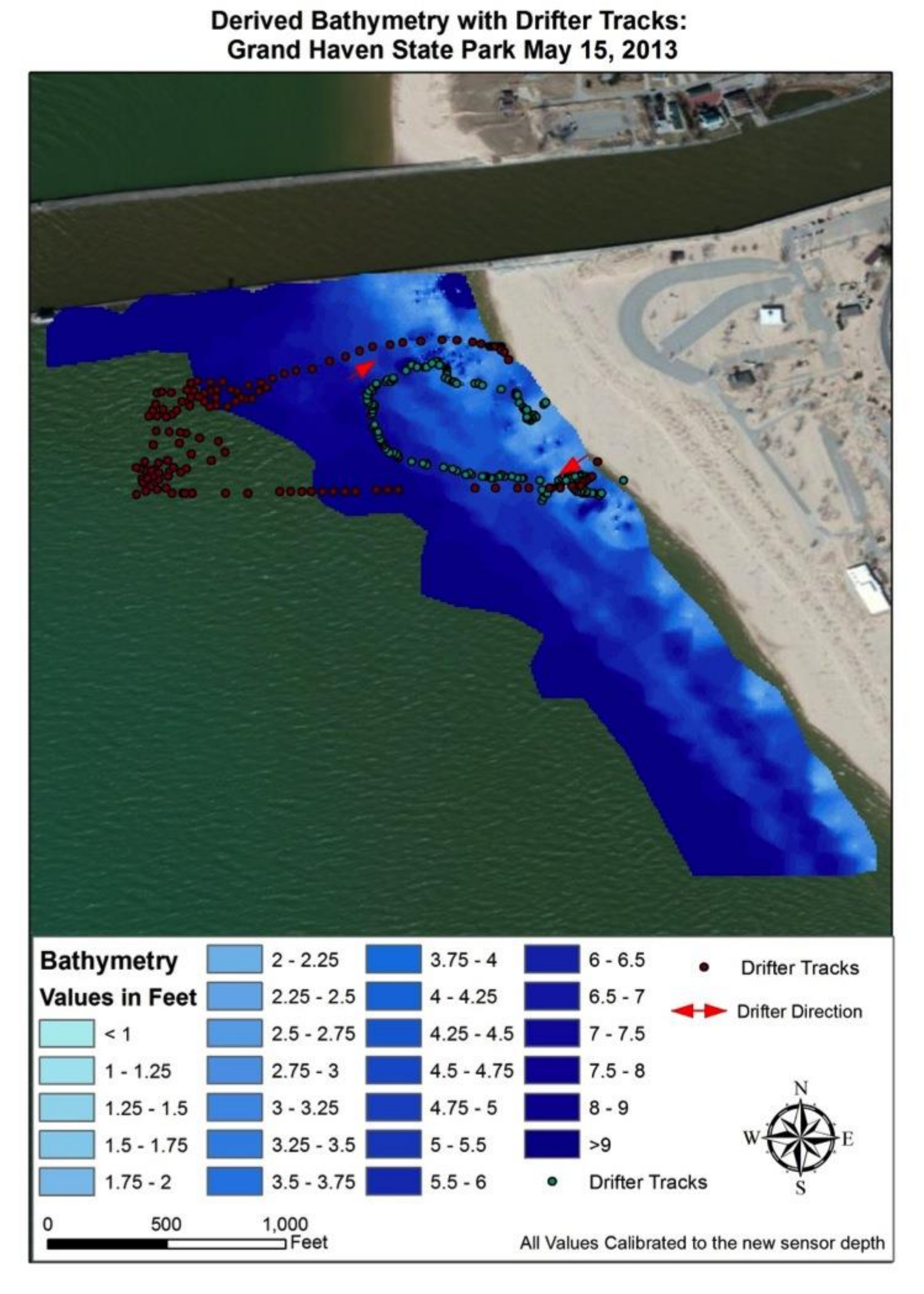
Pre and Post – Strom Bathymetry
Grand Haven State Park



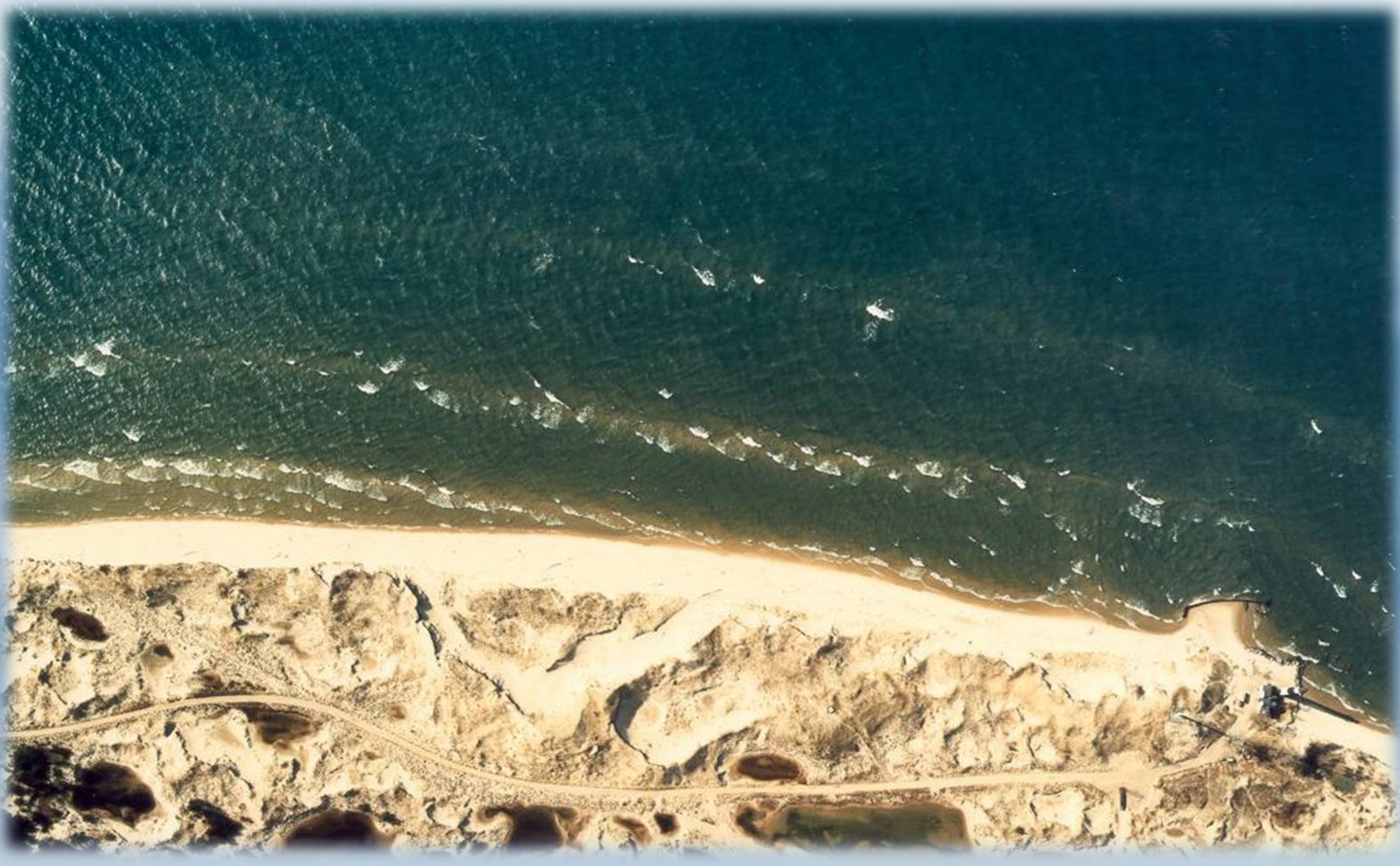


Drifter Tracks and Velocities

- At the Grand Haven State Park beach, both drifters were carried quickly offshore, floated slowly north and were pushed back towards the beach
- Average drifter velocity in the rip current was 0.3 m/s, maximum was 3.6 m/s
- The two drifters were carried 175 m and 400 m offshore and took approximately an hour to return to the shoreline.



Multiple Straight Bars



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Takeaways….

- **Almost all Great Lakes sand beaches have DNCs**
- **DNCs Develop Rapidly with increasing wave height**
- **Nearshore bottom is continually readjusting to waves and currents**
- **Rip channels can migrate down the beach   (Safe → Unsafe)**
- **DNCs persist long after waves subside**

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